Methods for Incorporating an Undersampled Cell Phone Frame When Weighting a Dual-Frame Telephone Survey

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I. Background

As of 2011, 87 percent of all households have cell phone (wireless) service based on estimates derived by the National Center for Health Statistics (NCHS) (Blumberg and Luke, 2011), which is now greater than the number of households with landline service (currently estimated at 68 percent). This finding has serious implications for any survey conducted by telephone, as 32 percent of all households cannot be contacted through a traditional Random-Digit-Dialed (RDD) landline telephone survey. The situation for RDD landline surveys in which the target population is households with children is also severe, as 36.4 percent of children live in households with only cell phone service (Blumberg & Luke, 2011).

As a result of the high and continuously growing percentage of people living in cell-phone only (CPO) households, traditional RDD landline surveys are subject to bias due to noncoverage of this population. Compared to the general population, the CPO population tends to have higher percentages of young adults, Hispanics, lower income levels, and renters. In addition to potential noncoverage bias associated with CPO households, there is also the potential for nonresponse bias associated with the cell-phone-mostly (CPM) population. The CPM domain, which encompasses 17 percent of adults, are "dual-users" (those that have both landline and cell phones), but may be less likely to actually answer their landline telephone because they receive all or nearly all calls on their cell phones[1] (Blumberg & Luke, 2011). The CPM population differs from the CPO population. Compared to the general population, the CPM population tends to have higher percentages of home owners, higher education levels, and higher income levels.

Given these demographic and telephone-answering behavior differences, it becomes increasingly necessary to consider fielding a dual-frame RDD design with both a landline and cell phone component to lessen the potential for bias. There are multiple ways that a dual-frame sample design can be implemented. First, and potentially easiest, is to screen the cell phone sample for the CPO population and interview only the CPO population via the cell phone frame. The CPM population would be eligible for interviews only as members of the landline frame. This allows for a non-overlapping dual-frame design for ease in creating estimation weights, but does not take into account the potential for higher levels of nonresponse from the CPM population.

A second solution is to screen the cell phone sample for both the CPO and CPM populations. This design addresses the potential for nonresponse of the CPM population in the landline frame, but is dependent upon accurate screening questions to reach those that are less likely to answer their landline telephone. With this option, there is also a need to construct dual-frame weights that address the resulting overlap from the dual-users and differential levels of nonresponse. A final option is to field the full cell phone sample with no screening. While this approach reduces costs compared to the other designs (since no screening is required), it creates significant overlap between the cell and landline telephone frames that needs to be addressed in weighting. While in general this is a less costly solution in terms of the total number of completed surveys, this produces a smaller number of CPO completes for a fixed cost.

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[1] In the National Health Interview Survey (NHIS), telephone status is determined through responses to the question posed of dual-user households "Of all the telephone calls that you and your household receive, are nearly all received on cell phones, nearly all received on regular phones, or some received on cell phones and some received on regular phones?" The CPM domain is defined as those dual-users who respond "nearly all received on cell phones."

In addition to determining how to include a cell phone frame in a telephone survey, the sample size for the cell phone frame needs to be established. In general, it is costlier to field a cell phone sample than a landline telephone sample (AAPOR, 2010). The cost of a cell phone sample completion may be as much as four times as expensive to obtain as a comparable landline completion. Therefore, dual-frame sample designs typically select cell phone samples at a rate smaller than that suggested based upon population distributions. Additionally, the cell phone sample may be drawn at a different geographic level than the landline telephone sample. For example, a national cell phone sample design may be integrated with a state-level landline telephone sample design, because of cost or ease of implementation.

All this can lead to differential probabilities of selection between the landline and cell phone sample frames. This differential can lead to significant increases in the variance of the estimates produced by the survey. Depending on how the cell phone sample is integrated, estimation weights also need to account for the overlap in frames if dual-users are included in the cell phone sample, and in such a way as to minimize the effect of the differential probabilities of selection, due to the higher probability of selection associated with the landline sample in many cases (i.e., the landline telephone sample has a larger relative size than the cell phone sample). Thus, careful consideration is required when creating estimation weights.

This paper will introduce a method for attenuating the cell phone sample weights with the objective of reducing the variance of the estimates. This research was prompted by large design effects created in the original 2009-2010 National Survey of Children with Special Health Care Needs (NS-CSHCN) weighting, where the landline and cell phone sample distribution was not reflective of the population distribution.

II. Survey Implementation

The goals of the 2009-2010 NS-CSHCN were to estimate the prevalence of children with special health care needs (CSHCN), gather information on the health and well-being of CSHCN, assess the impact of caring for CSHCN on families (e.g., insurance coverage, access to needed services, functional difficulties), and evaluate change from prior survey years (2001, 2005-2006). All estimates needed to be created at the state level. The survey was sponsored by the Federal Maternal and Child Health Bureau (MCHB) and fielded by NORC at the University of Chicago for NCHS.

The target population was households with children under the age of 18 years. For households with at least one age-eligible child, a series of basic demographic questions were asked, such as income, housing status, and family structure. All children within these households were also screened for the presence of CSHCN. If a CSHCN lived in the household, a longer questionnaire was administered. If there were multiple CSHCN in a household, one was randomly selected to be the subject of the detailed interview.

The 2009-2010 NS-CSHCN was fielded for six quarters starting Q3/2009 and continuing through Q4/2010. The landline telephone sample was fielded during all six quarters, but the cell phone sample was fielded only during the last two quarters of the survey (Q3/2010-Q4/2010). In total, nearly 7.8 million telephone sample lines were fielded for NS-CSHCN data collection, 14.7 percent of which were from the cell phone frame. During the six active quarters, 196,159 completed household interviews were obtained, 9.4 percent of which were from the cell phone sample (Table 1).

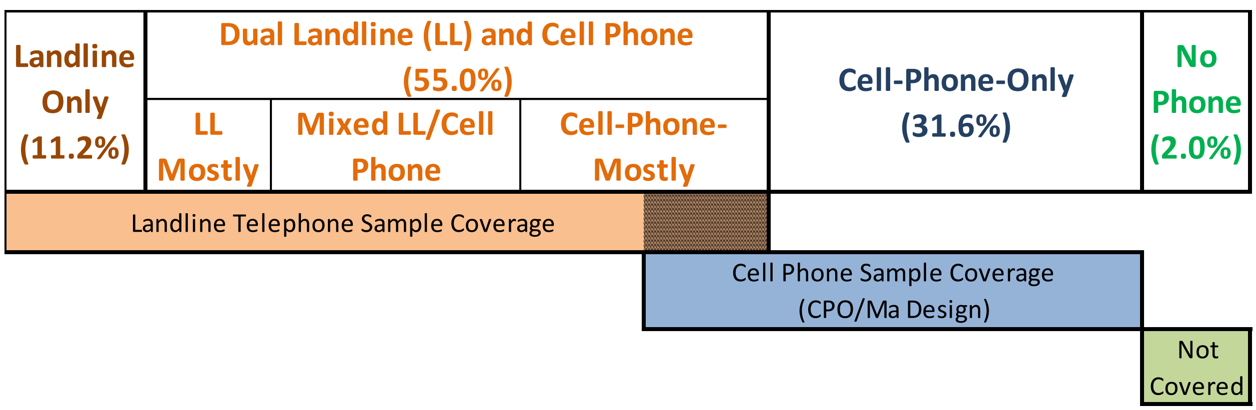
Table 1. Number and Percentage of Landline and Cell Phone Samples and Interviews.

	Data Collection	Released Sample	Percent of Released Sample	Household Interviews	Percent of Interviews
LL	Q3/2009 - Q4/2010	6,643,010	85.3%	177,672	90.6%
Cell	Q3/2010 - Q4/2010	1,140,661	14.7%	18,487	9.4%
Total	Q3/2009 - Q4/2010	7,783,671		196,159	

The NS-CSHCN cell phone sample was screened for both the CPO population, as well as for a subsample of the dual-users. These dual-users are called Cell-Phone-Mainly[2] (CPMa). Note that the screening question for identifying CPMa households differs from the screening question for identifying CPM households: the former being defined by how likely they are to answer their landline telephone, the latter being defined by the proportion of all calls that are received on their landline telephone. The CPMa screening question was implemented in NS-CSHCN to minimize the overlap between the landline and cell phone samples by interviewing those households that were less likely to be captured through the landline telephone sample. For ease of notation, the combined CPO and CPMa domain will be denoted as CPO/Ma.

Figure 2 shows the spectrum of household telephone status and the corresponding sample coverage resulting from a dual-frame design that screens for CPO/Ma. The telephone status spectrum ranges from the landline-only population through the CPO population, as well as the no-phone population. The landline telephone sample coverage, shaded in orange, shows the assumed coverage offered – including both the landline-only and dual-user domains. The portion of the landline telephone sample coverage in hash marks represents dual-users who are somewhat unlikely or not at all likely to answer their landline telephone. This segment of dual-users are covered by the sampling frame but potentially not represented in the resulting sample due to nonresponse. The area shaded in blue represents the cell phone sample coverage, which includes both the CPO domain and a portion of the dual-user domain. For purposes of illustration, it is assumed the CPMa domain is a subset of the CPM domain; however, in practice the CPMa domain may encompass some of the landline mostly and landline/cell mixed domains. The landline-only domain constitutes 11.2 percent of all households, while dual-users constitute 55.0 percent and CPO households constitute 31.6 percent. The no-phone population, which is not covered under a telephone sample design, constitutes only 2.0 percent of the population (Blumberg and Luke, 2011).

Figure 2. Spectrum of Household Telephone Status and Assumed Coverage of NS-CSHCN Dual-Frame Landline plus Cell Phone Design.



From the NS-CSHCN, there were 372,698 children rostered and screened for CSHCN living in the 196,159 households that were interviewed. These children were weighted to represent the full population of non-institutionalized children ages 0-17, and the prevalence rate of CSHCN was estimated. While the survey was able to cover the entire target population, with the exception of the no-phone population, the sample distribution was significantly different than the population distribution by telephone status. Table 2 shows summary information relative to state-level distributions of both population estimates and the distribution of the NS-CSHCN sample. The NHIS estimates are those presented in Blumberg et al. (2011) and are considered the best available population estimates; the median state-level estimate of the percent of children living in CPO households is 28.8 percent. In contrast, the median percentage of NS-CSHCN interviews coming from CPO households was 7.0 percent. The

[2] Within the NS-CSHCN, CPMas are identified through the question asked of dual-users "Thinking just about the landline home phone, not your cell phone, if that telephone rang and someone were home, under normal circumstances how likely is it that it would be answered? Would you say extremely likely, somewhat likely, somewhat unlikely, or not at all likely?" The CPMa domain was defined as those cases answering "not at all likely" or "somewhat unlikely."

median percentage of the combined CPO/Ma household completes is still only 9.3 percent of the total number of completes. These CPO and CPO/Ma sample distributions are much lower than the equivalent population distributions and lead to much higher sampling weights for the cell phone sample relative to the landline telephone sample.

Table 2. Minimum (Min), Median, Maximum (Max), and Interquartile Range (IQR) of State-level Cell-Phone-Only (CPO) and Cell-Phone-Only/Mainly (CPO/Ma) Population Estimates and NS-CSHCN Sample.

		Min	Median	Max	IQR (percentage points)
NHIS	CPO	12.60%	28.80%	46.20%	14.3
CSHCN State Design	CPO	4.04%	6.98%	18.55%	2.3
	CPO/Ma	5.00%	9.30%	22.20%	2.9

III. Original Weighting

The first step in any weighting process is to create a baseweight, which is the inverse of the probability of selection for a sampled telephone number. The baseweight is directly related to the relative sample size within each frame. As seen in Table 3, the landline telephone sample (LL) had baseweights ranging from 2.6 to 1,264.7, with a median of 28.4. In contrast, the cell phone sample (Cell) had baseweights ranging from 37.6 to 9,563.4. The median cell phone sample baseweight of 294.0 was over 10 times that of the median landline baseweight. As an additional measure, the Coefficient of Variation (CV) was calculated as the normalized measure of dispersion of the baseweights, where the absolute value of the CV is the Relative Standard Error (RSE). The CV within each sample was similar, 125.7 for landline and 177.1 for cell; however, for the combined landline and cell phone samples, the variability of the baseweights was much greater, as indicated by the CV of 297.3. Note that the CV in Table 3 represents the variability in the weights, not the relative variance of estimates from the sample.

Table 3. Count, Minimum (Min), Median, Maximum (Max), and Coefficient of Variation (CV) of Baseweights, by Frame.

	n	Min	Median	Max	CV
LL	6,643,010	2.6	28.4	1264.7	125.7
Cell	1,140,661	37.6	294.0	9563.4	177.1
LL+Cell	7,783,671	2.6	35.9	9563.4	297.3

The next step in the process was to create estimation weights. The original process allowed the CPO/Ma sample to be weighted up to represent the full CPO/Ma population. The differential in weights between the landline and cell phone samples resulted in survey estimates with large design effects. Figure 3 shows the distribution of state-level design effects for the prevalence rate of CSHCN under the original dual-frame weighting. The design effects range from 1.5 to 8.4, with a median of 3.4. In contrast, Figure 4 shows the distribution of the design effects based solely on the landline sample, with almost all state-level design effects using the landline sample between 1.3 and 2.0, and the highest design effect being 3.8.

Figure 3. Distribution of State Design Effects of Original Dual-Frame Weights.

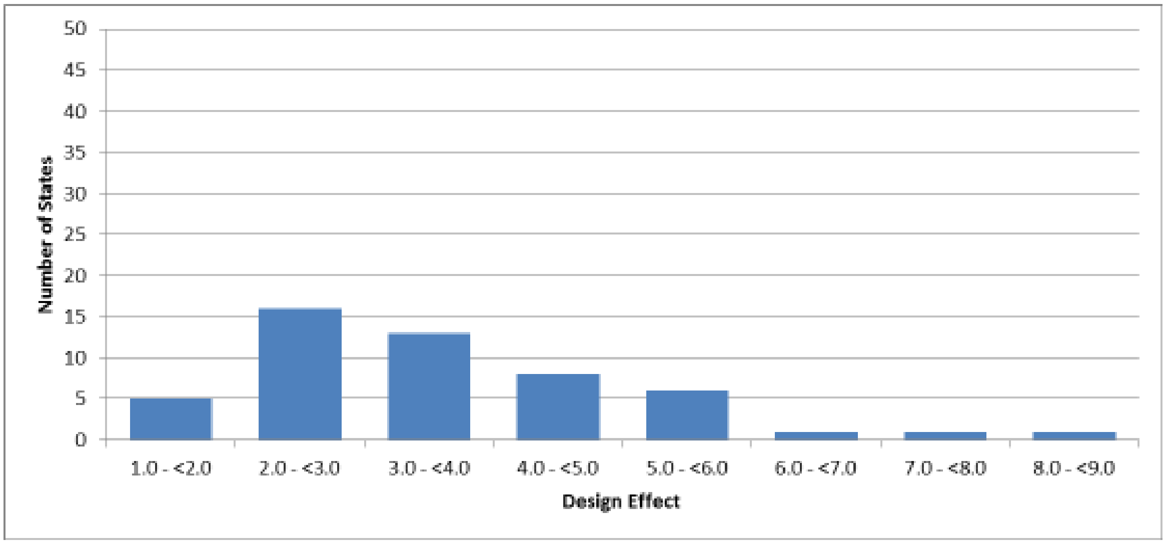
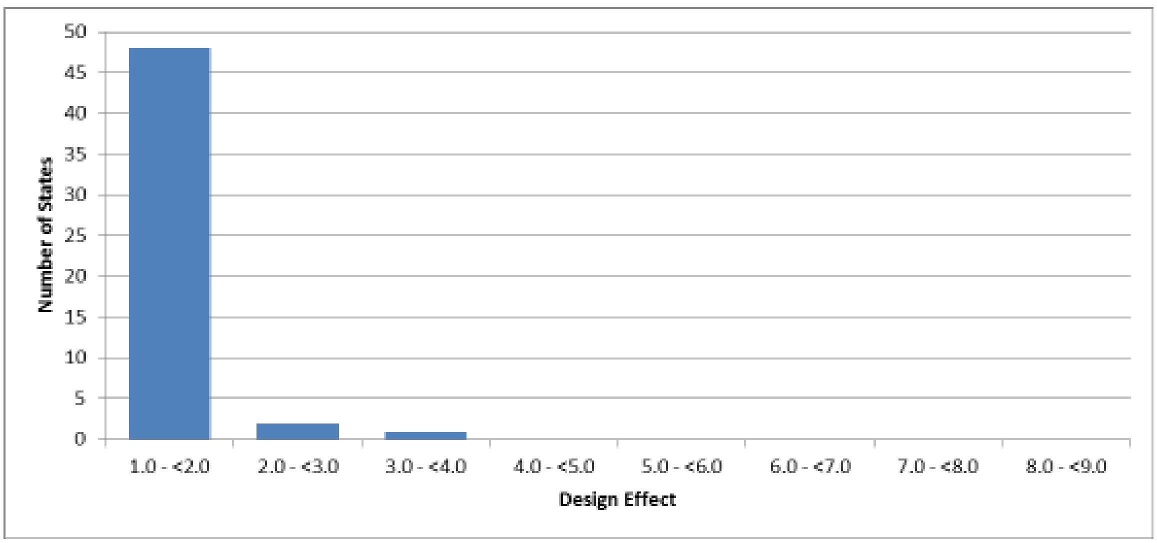


Figure 4. Distribution of State Design Effects of Landline Weights.



IV. Alternative Weighting

Because the design effects were so large, an alternative weighting method was sought to reduce the variability in the weights and, hence, reduce the design effects. The original method weighted the cell phone sample (which constituted nine percent of the total sample) to represent the full CPO/Ma domain (which represented 33 percent of the total population). The landline telephone sample was then weighted to represent the remainder of the population, i.e., the landline only and dual-users (less CPMa) domains, plus the no-phone domain.

In the alternative method, the cell phone sample weights were attenuated with the objective of minimizing the Mean Squared Error (MSE) of selected survey estimates, thereby addressing the issue of variance while also seeking to control the bias of the estimates. To attenuate the cell weights, a compositing approach was developed to combine the cell phone sample and a subset of the landline telephone sample (identified through a propensity model as being similar to CPO/Ma, and referred to here as proxy CPO/Ma) to derive estimates for the cell phone sample. The estimates for the cell phone sample under this compositing approach are defined as

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where

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and and represent the estimates of the variable of interest based on the cell phone sample and the landline telephone sample, respectively, and represent the estimates of the variances of and , respectively, and represents the bias associated with and is defined by the difference between and .

The factor is based on the variance and bias associated with the proxy CPO/Ma sample in relation to the variance associated with the actual cell phone sample. If the bias and variance associated with the proxy CPO/Ma sample are greater than the bias and variance associated with the actual cell phone sample, this factor will be larger, and estimates for the CPO/Ma domain will rely more on the proxy CPO/Ma sample.

Ultimately, this alternative method resulted in the actual cell phone sample representing a smaller portion of the population based on the compositing factor. The actual cell phone sample was weighted to represent just 16 percent of the population rather than the original 33 percent of the population.

V. Results and Comparison

Ultimately, the alternative weighting method had the desired outcome of reducing the design effects. Figure 5 shows the state-level distribution of design effects for prevalence rates of CSHCN under the alternative method. The design effects ranged from 1.7 to 4.9, with a median design effect of 2.1. These design effects were significantly reduced relative to those from the original weighting plan, where the median was 3.4 and the maximum was 8.4.

Figure 5. Distribution of State-level Design Effects using Alternative Weighting.

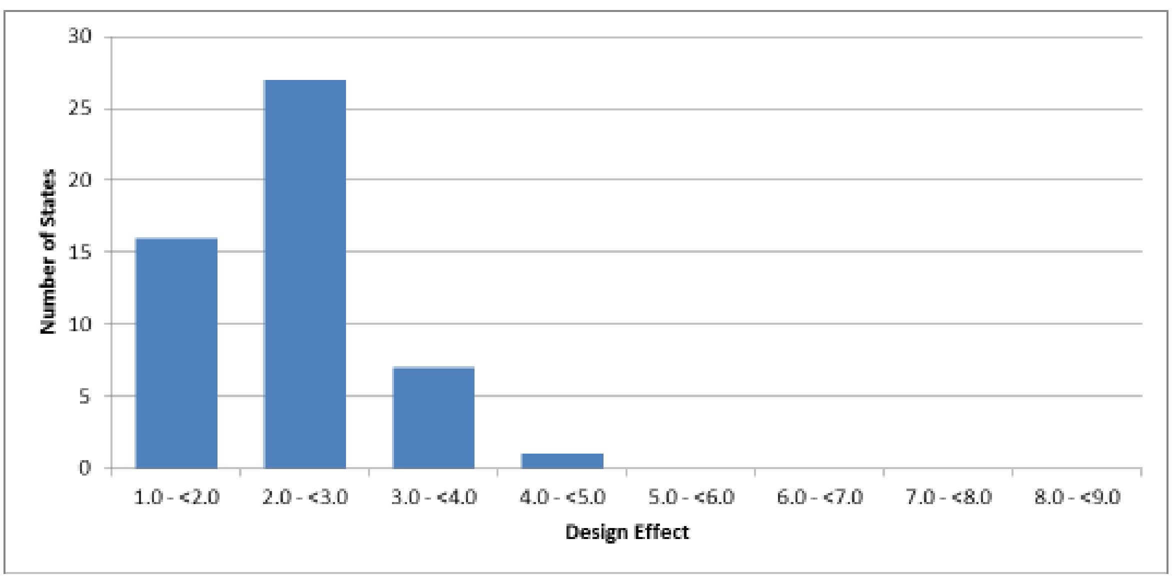


Table 4 shows the estimates, design effects, and standard errors associated with both the original and alternative weighting methodologies. Attenuating the cell phone sample weights by leveraging the proxy CPO/Ma sample created a slightly lower national prevalence rate, reducing it from 15.56 percent to 15.07 percent thus yielding a differential bias of 0.49 percentage points. However, the design effect was reduced 20 percent, from 5.1 to 4.1. The Root Mean Square Error (RMSE) was calculated under each method. For the original method, the RMSE is simply the square root of the variance, under the assumption that each estimate is unbiased. As seen in the table, the RMSE associated with the alternative method, 0.50, is much larger than the RMSE of 0.13 associated with the original method. This is due to the relatively small standard error associated with the estimates, which is likely a function of the sample size for the national estimate.

It is useful to note that it is assumed that the original method yields unbiased estimates against which to compare and calculate the bias associated with the alternative method. While this is the best practical application of determining the differential bias associated with the alternative weighting method, it does not take into account variance associated with each of the estimates. Therefore, the RMSE that is calculated is likely an overstatement of the actual RMSE associated with the alternative weighting method.

Table 4. National Children with Special Health Care Needs Prevalence Rate, Design Effect (DEFF), Standard Error (Std. Error), and Root Mean Square Error (RMSE) under the Original and Alternative Weighting Methods.

		Prevalence	DEFF	Std. Error	RMSE
National	Original	15.56%	5.11	0.13	0.13
	Alternative	15.07%	4.08	0.12	0.50

The state-level outcome is shown in Table 5. This shows the distribution of the state-level prevalence rates, design effects, differential bias, and RMSE. In general, the alternative method created slightly lower prevalence rates for the states, with the median prevalence rate reduced from 16.21 percent to 15.96 percent. While this added differential bias to the estimates, there was a 38 percent reduction in the median design effect, from 3.4 down to 2.1.

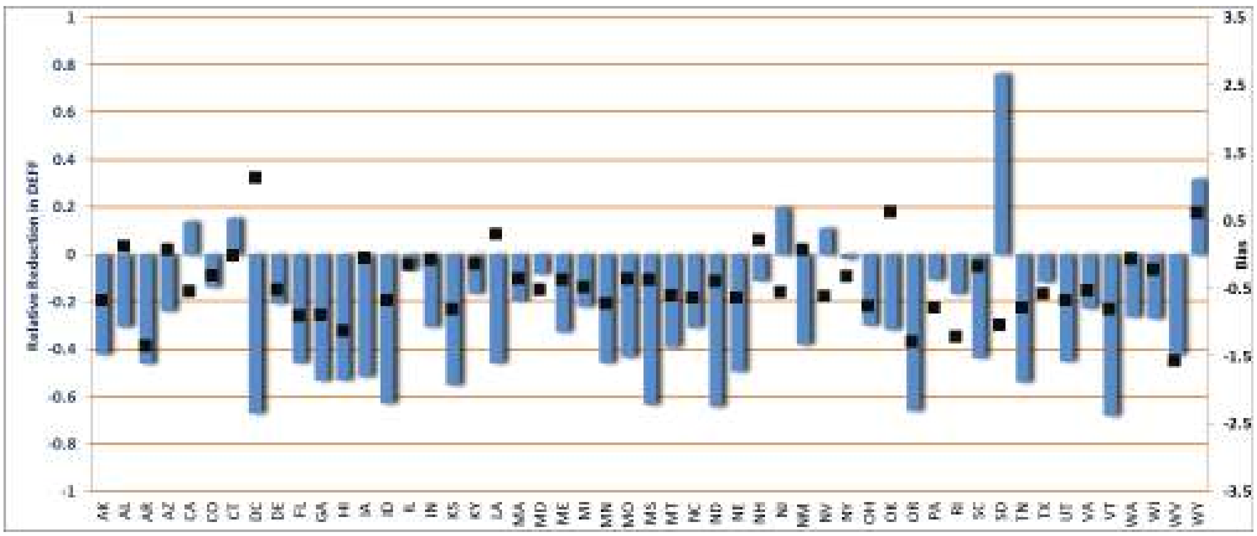
Under the original method, there were a handful of states that had extremely high design effects across the board, with D.C. and North Dakota having the highest for almost all of the estimates of interest from this survey. For the CSHCN prevalence rate, D.C. had the greatest reduction in design effect, from 8.4 down to 2.8 under the alternative method. The largest state-level design effect under the alternative method was 4.9 compared to 8.4 from the original method. The RMSE shows slight increases, again due to the relatively small standard errors associated with these estimates.

Table 5. Minimum (Min), Median, and Maximum (Max) State-level Children with Special Health Care Needs Prevalence Rate, Design Effect (DEFF), Absolute Differential Bias, and Root Mean Square Error (RMSE) under the Original and Alternative Weighting Methods.

		Min	Median	Max
State Prevalence	Original	11.13	16.21	21.10
	Alternative	10.59	15.96	19.75
DEFF	Original	1.54	3.38	8.39
	Alternative	1.72	2.08	4.93
Absolute Differential Bias	Original	0.00	0.00	0.00
	Alternative	0.02	0.56	1.56
RMSE	Original	0.42	0.78	1.29
	Alternative	0.58	0.85	1.72

Figure 6 shows the relative change in the design effect against the differential bias created under the alternative method for each state along the x-axis. The relative change in design effect is noted by the bars and associated with the y-axis on the left-hand side of the graph. The differential bias is noted by the squares and associated with the y-axis on the right-hand side of the graph. With the exception of six states, all other states showed a reduction in their design effect with minimal bias incurred. South Dakota was the state with the largest increase in design effect, but had a relatively small design effect under the original weighting methodology of only 2.8.

Figure 6. Relative Change in Design Effect (DEFF) and Differential Bias of State Prevalence Rates.



As mentioned above, a longer detailed questionnaire is administered to households where a CSHCN is identified. For the 2009-2010 NS-CSHCN, 40,243 detailed CSHCN interviews were completed. Of these, 2,991 were from the cell phone sample, or 7.4 percent of all completed CSHCN interviews. From this interview, there are six core outcomes and 15 key indicators that are estimated (U.S. Department of Health and Human Services, 2007). All 21 estimates had similar results. States with large reductions in design effect for one of the core outcomes or key indicators typically had large reductions in all the estimates. Therefore, the remainder of the results will focus on two key indicators: the percentage of currently insured CSHCN whose insurance was not adequate and the percentage of CSHCN whose families experienced financial problems due to child's health needs. Due to the smaller sample sizes overall and with the cell sample in particular, the results are more variable than those associated with the earlier special needs prevalence rates.

For CSHCN with inadequate insurance, the estimate using the alternative method yielded a differential bias of 0.17 percentage points, as seen in Table 6 below. However, there was a reduction in the design effect from 4.7 to 3.5, or a 27 percent decrease. The standard error of the estimate was reduced as well, from 0.52 to 0.45. Since the standard error was much larger than the prevalence rate, the RMSE is driven more by the reduction in the standard error than the introduction of the differential bias.

Table 6. National CSHCN with Inadequate Insurance Estimate, Design Effect (DEFF), Standard Error (Std. Error), and Root Mean Square Error (RMSE) under the Original and Alternative Weighting Methods.

		Estimate	DEFF	Std. Error	RMSE
National	Original	34.54%	4.74	0.52	0.52
	Alternative	34.37%	3.46	0.45	0.45

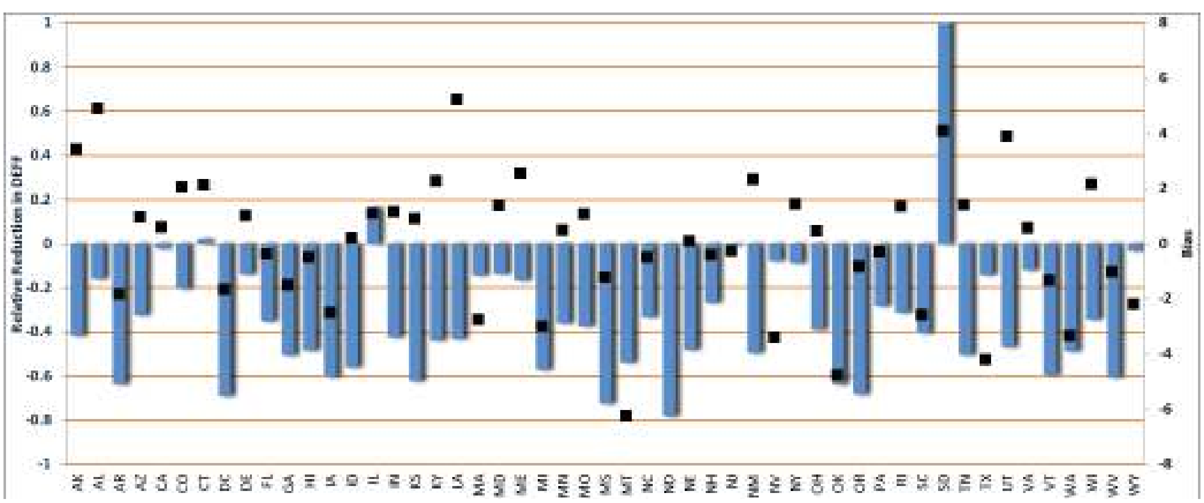
When reviewing the estimates of the percent of CSHCN with inadequate insurance at the state level, the impact is even more notable. While the median estimate increased slightly from 34.01 to 34.18, the median design effect was reduced by 38 percent, from 2.9 down to 1.8. North Dakota had the largest reduction in design effect, from 8.9 to 2.0. The median RMSE decreased from 2.9 to 2.7, though there was an increase seen for the maximum RMSE mainly due to the introduction of a larger differential bias.

Table 7. Minimum (Min), Median, and Maximum (Max) State-level CSHCN with Inadequate Insurance, Design Effect (DEFF), Absolute Differential Bias, and Root Mean Square Error (RMSE) under the Original and Alternative Weighting Methods.

		Min	Median	Max
Inadequate Insurance	Original	23.60	34.01	43.89
	Alternative	25.42	34.18	45.04
DEFF	Original	1.60	2.87	8.90
	Alternative	1.45	1.78	5.30
Absolute Differential Bias	Original	0.00	0.00	0.00
	Alternative	0.09	1.44	8.10
RMSE	Original	2.11	2.91	5.32
	Alternative	1.95	2.70	8.45

Figure 7 shows the relative change in the design effect for the estimates of the percent of CSHCN with inadequate insurance against the differential bias created under the alternative method for each state along the x-axis. The relative change in design effect is noted by the bars and associated with the y-axis on the left-hand side of the graph. The differential bias is noted by the squares and associated with the y-axis on the right-hand side of the graph. As with the special needs prevalence rates, there are a few states that saw an increase in design effect, but across the board there were significant reductions, although with more of an impact on the differential bias. As noted above, however, even with the introduction of the differential bias, the median RMSE decreased.

Figure 7. Relative Change in Design Effect (DEFF) and Differential Bias of State Estimates of CSHCN with Inadequate Insurance.



For estimates of the percent of CSHCN whose families experienced financial problems due to the child's health needs, the findings in Table 8 are similar to what was seen for estimates of inadequate insurance. The alternative method produced a slightly lower estimate of 21.56 percent compared to 21.77 percent under the original method. The design effect was reduced by 31 percent, from 5.3 to 3.7. As with the other key indicator, the standard error was reduced, which in turn, reduced the median RMSE from 0.47 to 0.39.

Table 8. National Estimate of Financial Problems due to CSHCN, Design Effect (DEFF), Standard Error (Std Error), and Root Mean Square Error (RMSE) under the Original and Alternative Weighting Methods.

		Estimate	DEFF	Std. Error	RMSE
National	Original	21.77%	5.27	0.47	0.47
	Alternative	21.56%	3.66	0.39	0.39

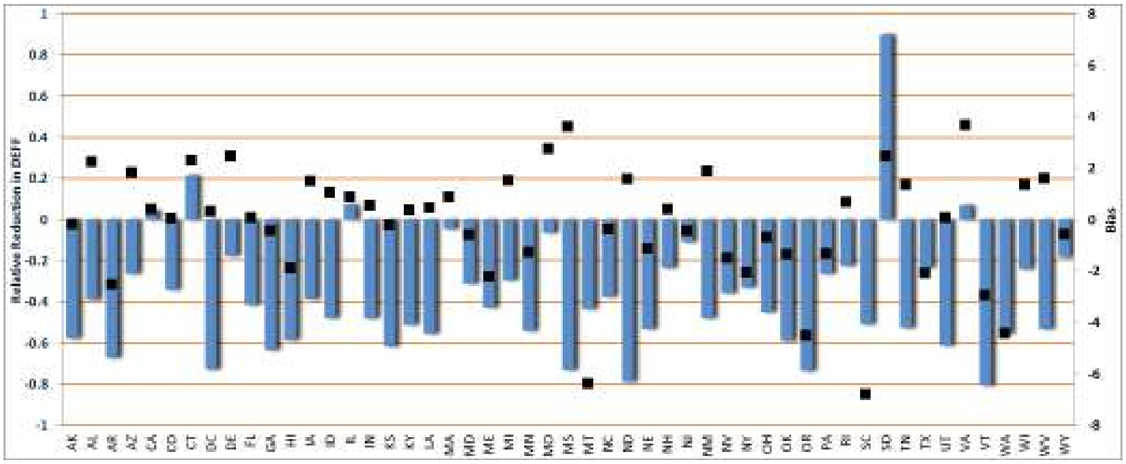
The state-level estimates showed more variability under the alternative method, but in general, an improvement over the original method, as shown in Table 9. The median estimate increased from 20.83 to 21.26, indicating a differential bias of 0.43 percentage points. There was a 42 percent decrease in the median design effect, from 3.2 to 1.9. Again, there was a reduction in the median RMSE even with the introduction of the differential bias, though the maximum RMSE did have an increase.

Table 9. Minimum (Min), Median, and Maximum (Max) State-level Rate of Financial Problems due to CSHCN, Design Effect (DEFF), Absolute Differential Bias, and Root Mean Square Error (RMSE) under the Original and Alternative Weighting Methods.

		Min	Median	Max
Financial Problems due to CSHCN	Original	14.02	20.83	36.20
	Alternative	13.99	21.26	29.81
DEFF	Original	1.45	3.22	10.28
	Alternative	1.41	1.87	5.73
Absolute Differential Bias	Original	0.00	0.00	0.00
	Alternative	0.04	1.35	6.79
RMSE	Original	1.60	2.72	4.61
	Alternative	1.68	2.44	7.13

Figure 8 shows the relative change in design effect and bias by state for the estimate of CSHCN whose families experienced financial problems. Again, South Dakota had the largest increase in design effect, but all other states had either a reduction or a negligible increase in design effect. The introduction of the differential bias was more variable at this level, but this was mitigated by the overall reduction in variance as shown with the RMSE results.

Figure 8. Relative Change in Design Effect (DEFF) and Differential Bias of State Estimates of Financial Problems due to CSHCN.



V. Conclusion

In general, CPO populations tend to be underrepresented in dual-frame RDD telephone surveys, due to the higher cost associated with fielding a cell phone sample. This leads to higher baseweights associated with the cell phone sample than with the landline telephone sample, creating a differential between the landline and cell phone sample weights, which increases the overall variance of the estimates. In this paper, we presented an approach to attenuating the cell phone sample weights to account for these large differences. This approach does introduce bias into the estimates, but can generate significantly smaller variances. In some instances it can reduce the overall RMSE even with the addition of differential bias.

While attenuating cell phone sample weights can be useful, there needs to be a balance between the introduction of bias versus the reduction in the variance of the weighted estimates. This solution chose to minimize the MSE to determine the degree to which the cell phone sample weights are dampened. There may be alternative statistics that could be reviewed, such as the CV of the weights or the bias of the estimates. In practice, it may be necessary to run simulations to determine the point of optimization. However, the degree of dampening may be subjective and depend on the balance between bias and variance.

In addition to statistical assessments, the data user should also be considered. While many who work on implementing these surveys and creating weights have experience balancing bias and variance, the end user may be more hesitant to accept the potential for increased bias as a reasonable cost for achieving smaller confidence intervals. When the attenuated weighting approach is used, these data users may require further explanations to become convinced of the benefits of the approach and to have faith in the resulting estimates.

Given the cost implications associated with cell phone samples, the issue of differential sampling weights between the landline and cell phone samples is something many surveys need to address when including a cell phone sample in their design. Attenuating cell phone sample weights is one way to effectively deal with increases in variance due to this differential. As shown in this example, the overall RMSE can be reduced even with the inclusion of some bias to the estimates.

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